

# Forest Hydrology: Lect. 2

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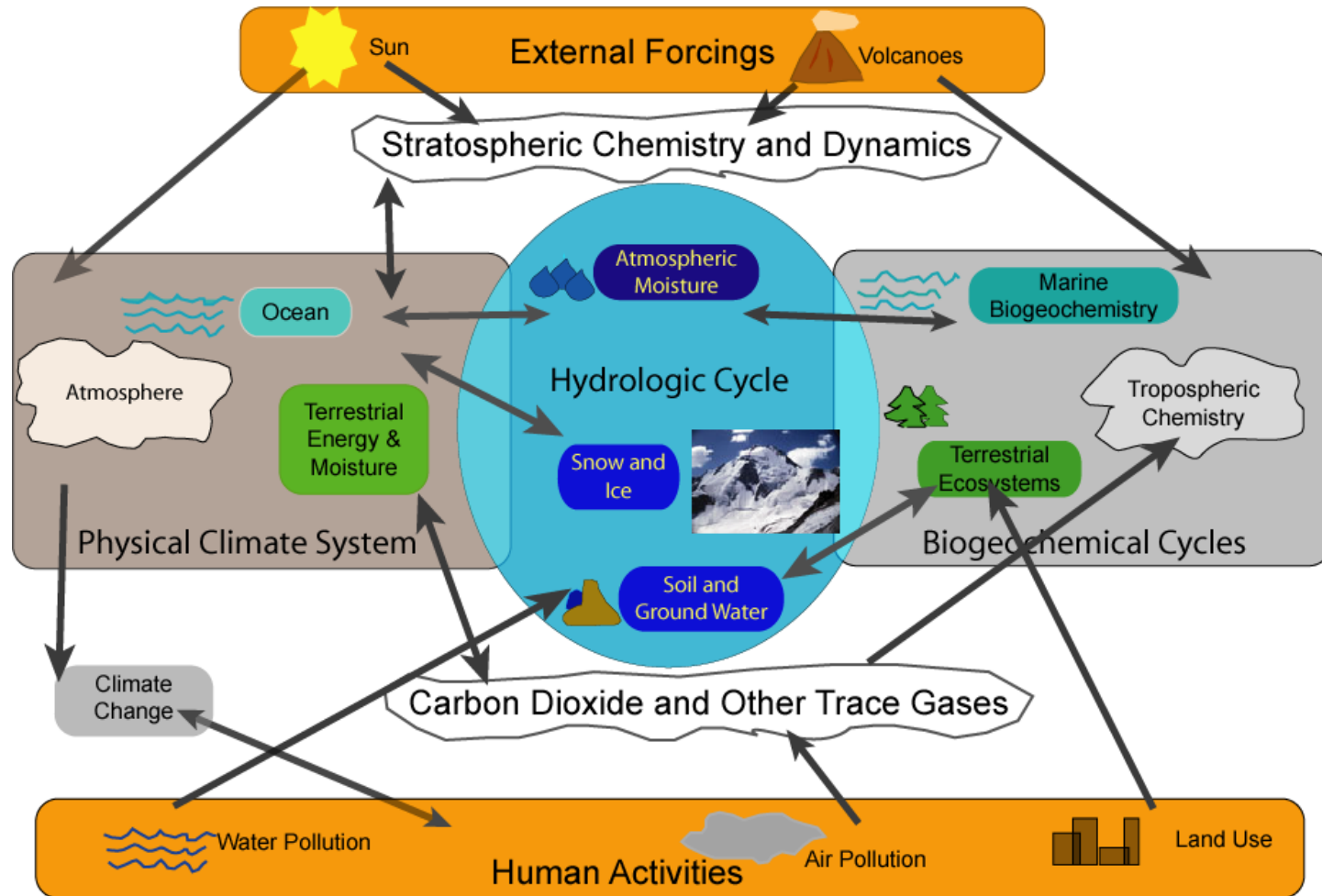
# Forest Hydrology: Lect. 2

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Why are the deserts there?



# Earth System: physical climate and biogeochemical systems, coupled by the hydrologic cycle



# The hydrologic cycle is driven by ...

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- Solar energy
  - Exchanges of this energy within the Earth system results in evaporation/condensation, freezing/thawing, changes of density
- Gravity
  - Wind (pressure gradients caused by gravity)
  - Rivers/glaciers flowing downhill
  - Groundwater moving because of potential energy gradients in the water

# Water on Earth (approx. $1.4 \times 10^9 \text{ km}^3$ )

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• Oceans	97.2%
• Ice	2.0
• Groundwater - deep (750-4000m)	0.4
• Groundwater -shallow (<750m)	0.3
• Lakes	0.01
• Soil	0.005
• Atmosphere	0.001
• Rivers	0.0001
• Biosphere	0.00004

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Read: Black, P.E. On the critical nature of “useless” resources; *Water Resources Bulletin* (1995)

# Never at Rest ....

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Water moves continually between the reservoirs by a number of processes:

- *Evaporation* from the ocean, *precipitation* onto the ocean, transfer of a portion over continents
- *Precipitation* on continents (rain, snowfall, snowpack storage and meltwater release)
- *Evaporation* from continents (if it occurs directly from a water surface or soil surface), *evapotranspiration* if the evaporation is modulated by plant processes.
- *Infiltration*
- *Percolation* through soils and rocks
- *Streamflow* (stormflow and baseflow); flow through lakes
- Flow through the ocean
- Evaporation from the ocean ..... etc., etc.

**Energy (and its spatial variability) is the key to the continual transfer of water mass**

# Fluxes between stores

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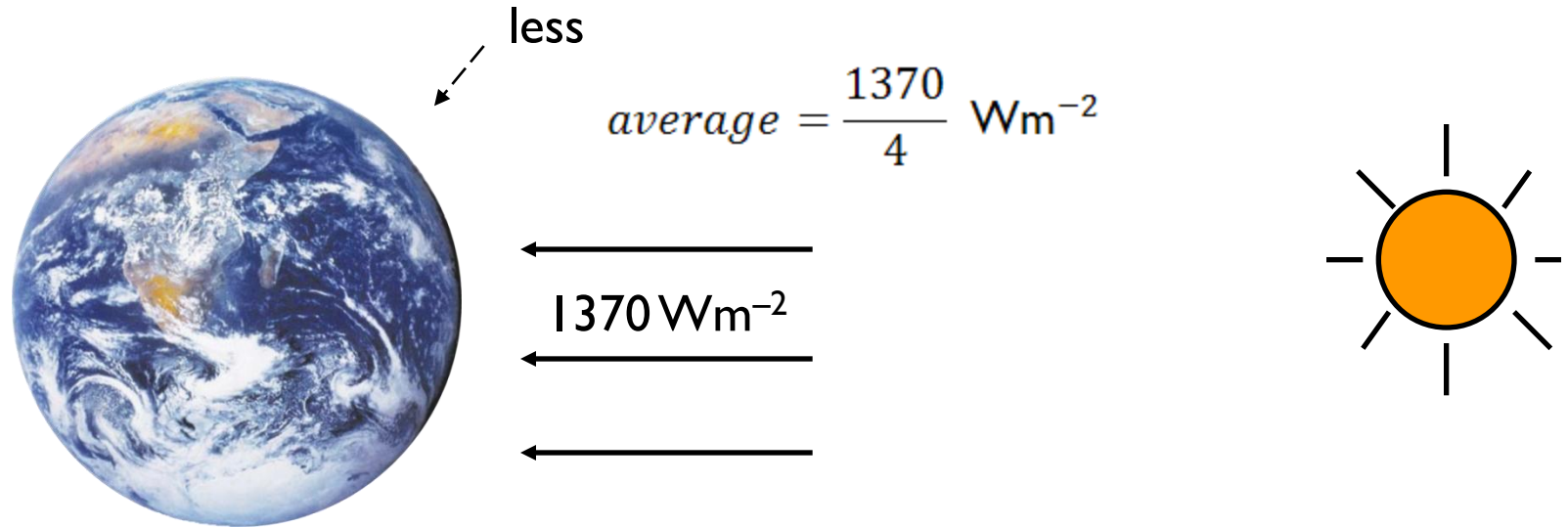
Note that the ocean area is about twice the land area; these numbers are in volumes per unit area of surface)

Evaporation from ocean	117 cm/yr
Precipitation onto ocean	107 cm/yr
Precipitation onto land	74 cm/yr
Evaporation from land	49 cm/yr
Runoff from land	25 cm/yr

Over the ocean,  $E > P$

Over land,  $P > E$ . Suggests that the storage of water on land causes some kind of "resistance" to evaporation, so that some of the precipitated water "escapes" evaporation and survives to run off the continents as streamflow (R).

# How Earth operates (simplified)

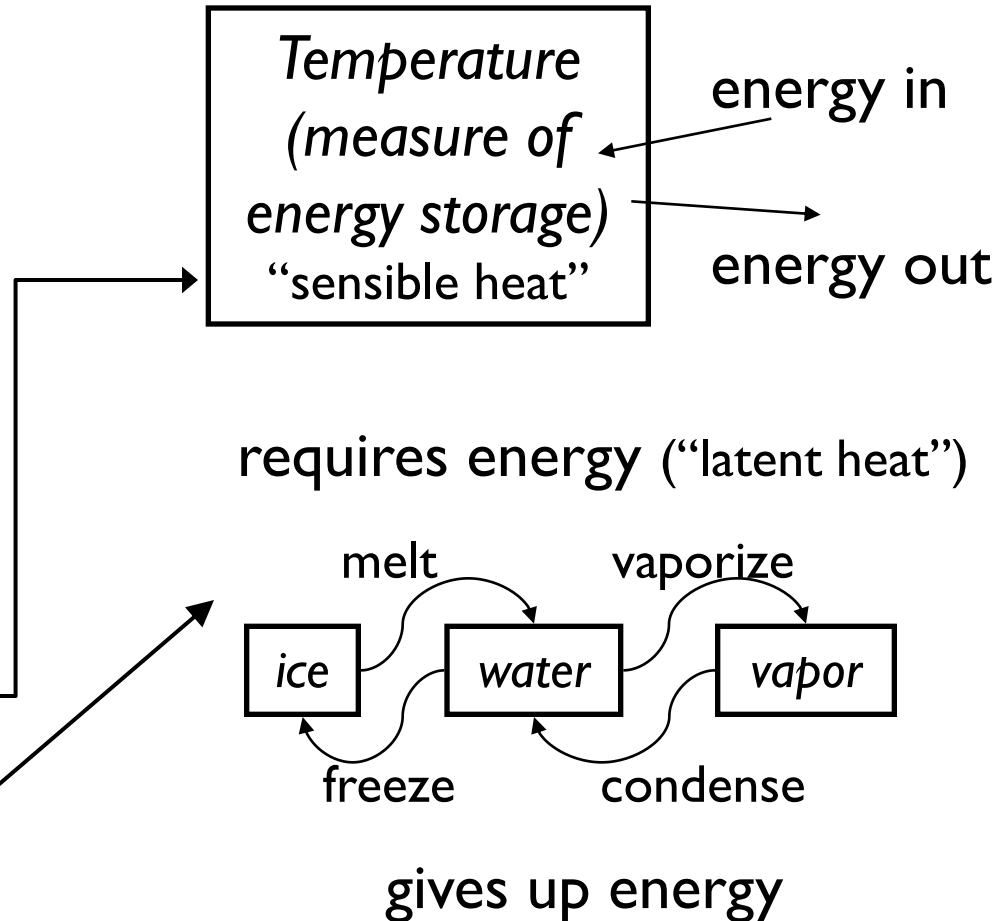


- Some fraction (20-30%) is *reflected* by atmosphere and surface
  - Remainder (70-80%) is *absorbed* and emitted at longer wavelengths
    - Some emitted radiation is absorbed in atmosphere
  - Imbalance between Equator and Poles causes circulation of atmosphere and ocean
  - Heated surface transfers energy to atmosphere
  - Water at surface evaporates and moves into atmosphere
    - ... and condenses to fall back to surface as precipitation
- } and the energy also moves



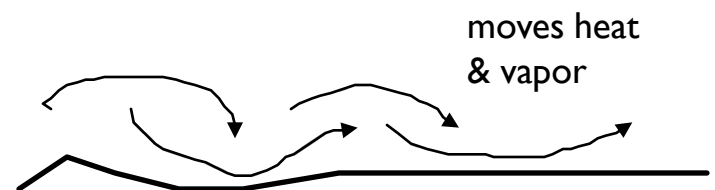
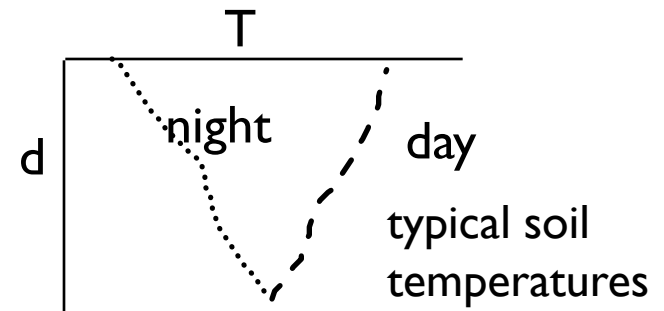
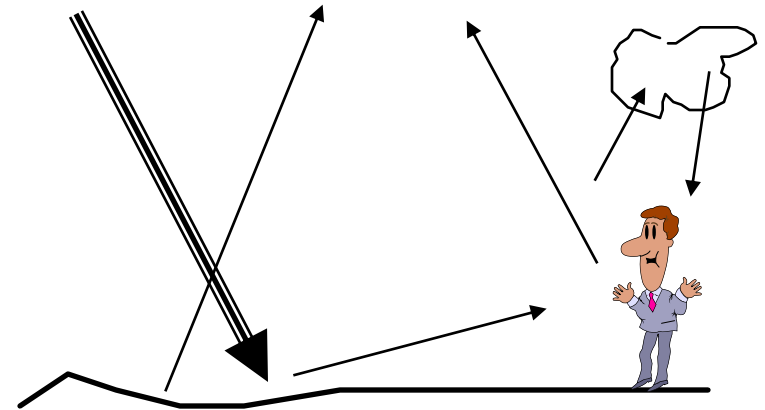
# Energy balance principles

- Energy is the capacity for doing work (i.e. motivating some change in a system)
- “Energy” and “heat” are equivalent
- Energy in – energy out =  $\Delta$  energy storage
- $\Delta$  energy storage  $\equiv$  either
  - $\Delta$  temperature
  - $\Delta$  “phase” of water (solid, liquid, gas)

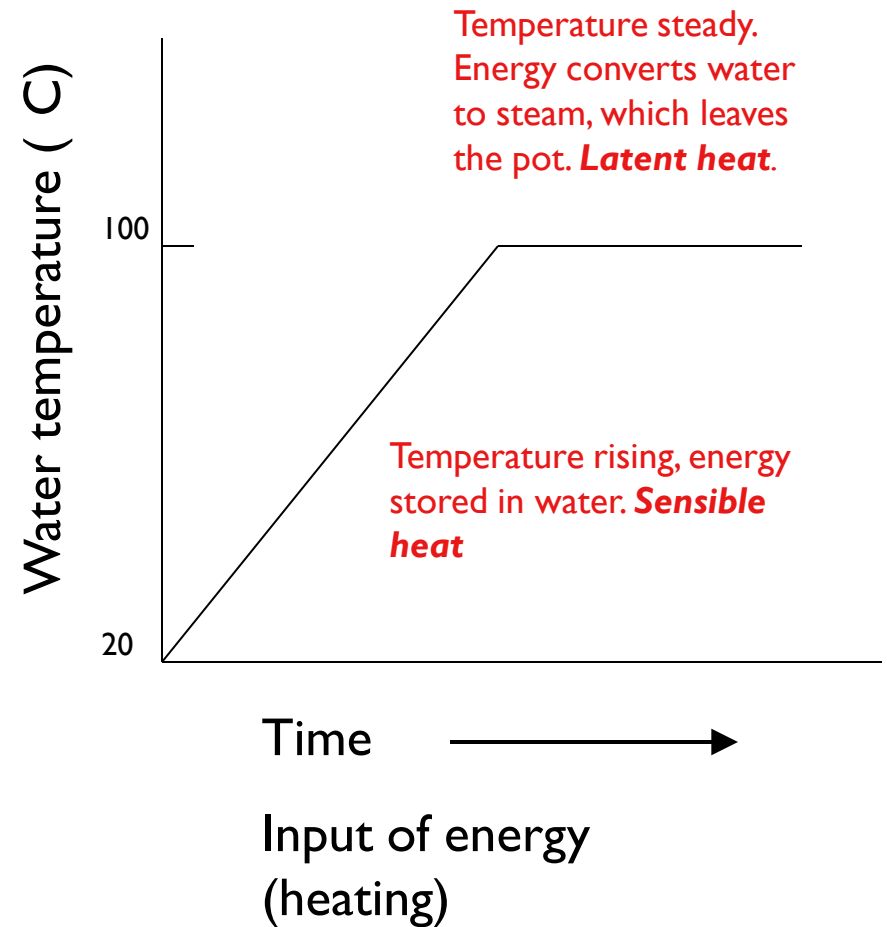


# Methods of energy transfer

- **Radiation:** electromagnetic waves propagate through space
  - all bodies radiate, warmer bodies more
  - interactions depend on wavelength
- **Conduction:** molecule-to-molecule
  - hot to cold temperature
- **Convection:** mixing in air or water enhances transfer
  - sensible: temperature difference between warmer and colder fluid
  - latent: change of phase of water during mixing



# Sensible and latent heat



# Radiation

- A body radiates energy when electrons in its atoms receive or generate so much energy that they release a small packet of energy (photon)
- If the atoms are receiving or generating a lot of energy (i.e. they are hot) they emit photons in large numbers and frequently. Thus, both the intensity (energy per unit time) and the frequency of emission are high.
- Since energy ( $E$ ) travels through a vacuum at a constant speed ( $c$ , the speed of light), if the frequency ( $\nu$ ) of particle (wave) emission is high, the wavelength ( $\lambda$ ) is short:  $\nu = c/\lambda$
- Planck's law: energy per photon =  $h\nu = h/\lambda$

$h$  is Planck's constant

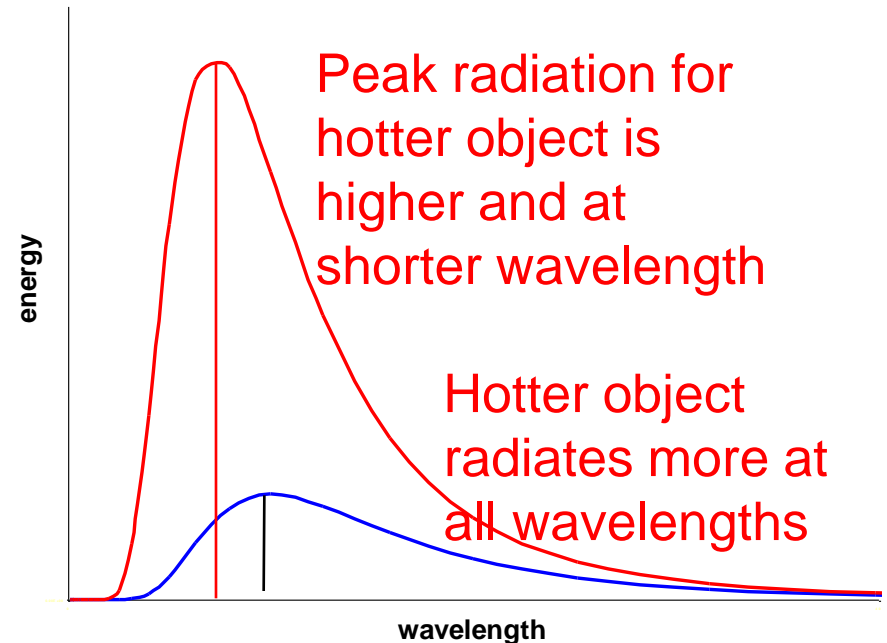
# Two rules describing radiation:

## 1. *Planck's equation*

- *Planck's equation*

$$L_{\lambda} = \frac{2hc^2}{\lambda^5 e^x - 1}, \text{ where } x = \frac{hc}{k\lambda T}$$

- At a given temperature a body emits a spectrum of wavelengths and the intensity of radiation varies with the wavelength



$c$  = speed of light =  $3.0 \times 10^8 \text{ ms}^{-1}$

$h$  = Planck's constant =  $6.63 \times 10^{-34} \text{ Js}$

$k$  = Boltzmann's constant =  $1.38 \times 10^{-23} \text{ JK}^{-1}$

# Integration over all wavelengths (derived from Planck's equation)

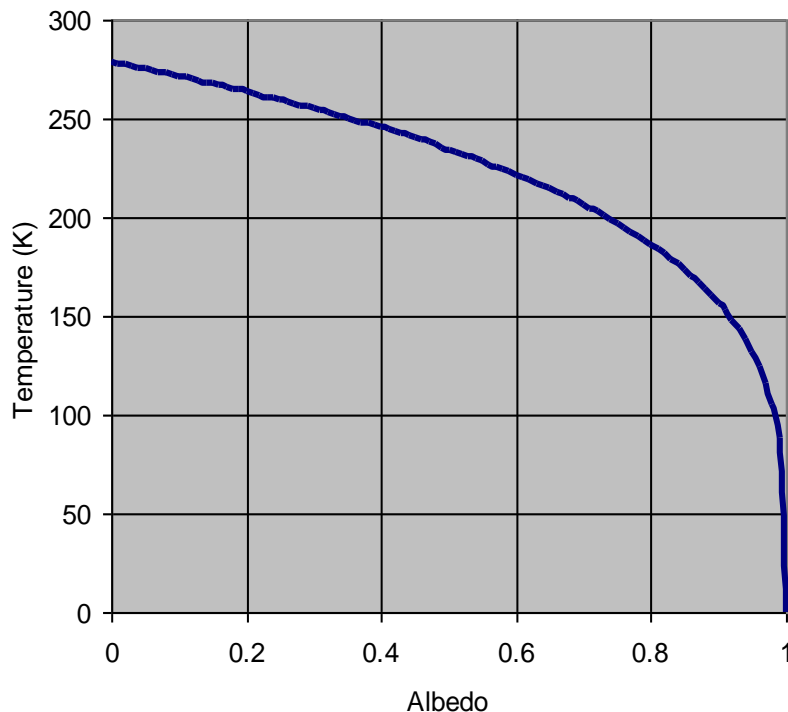
- *Stefan-Boltzmann equation*

$$E = \pi \int_0^{\infty} L_{\lambda} d\lambda = \varepsilon \sigma T^4$$

- $E$  = energy emitted ( $\text{W m}^{-2}$ )
  - $T$  = temperature ( K)
  - $\sigma$  = Stefan-Boltzmann constant =  $5.67 \times 10^{-8} \text{ W m}^{-2} \text{ deg}^{-4}$
  - $\varepsilon$  = emissivity (ratio of radiation from the material to that from an ideal 'blackbody' at same temperature). 0.9-0.99 for most natural materials, but 0.01-0.05 for aluminum foil, for example.
- 
- Energy from the Sun ( $T = 5800 \text{ K}$ ) =  $6.4 \times 10^7 \text{ W m}^{-2}$
  - Energy from Earth ( $T = 288 \text{ K}$ ) =  $390 \text{ W m}^{-2}$

# The simplest climate model—energy balance with a non-absorbing atmosphere

- Solar radiation absorbed by whole Earth = infrared radiation emitted by whole planet  
 – *i.e., net all-wave radiation = 0*
- $S_0$  = solar radiation
- $\alpha$  = planetary average albedo
- $F_{\square}$  = infrared radiation
- $T$  = planetary surface temperature



$$\frac{S_0}{4} (1 - \alpha) = F_{\uparrow} = \epsilon \sigma T^4$$

$$so, T = \left[ \frac{S_0}{4\epsilon\sigma} (1 - \alpha) \right]^{1/4}$$

$$- \epsilon \approx 0.90-0.95, \sigma = 5.67 \cdot 10^{-8}$$

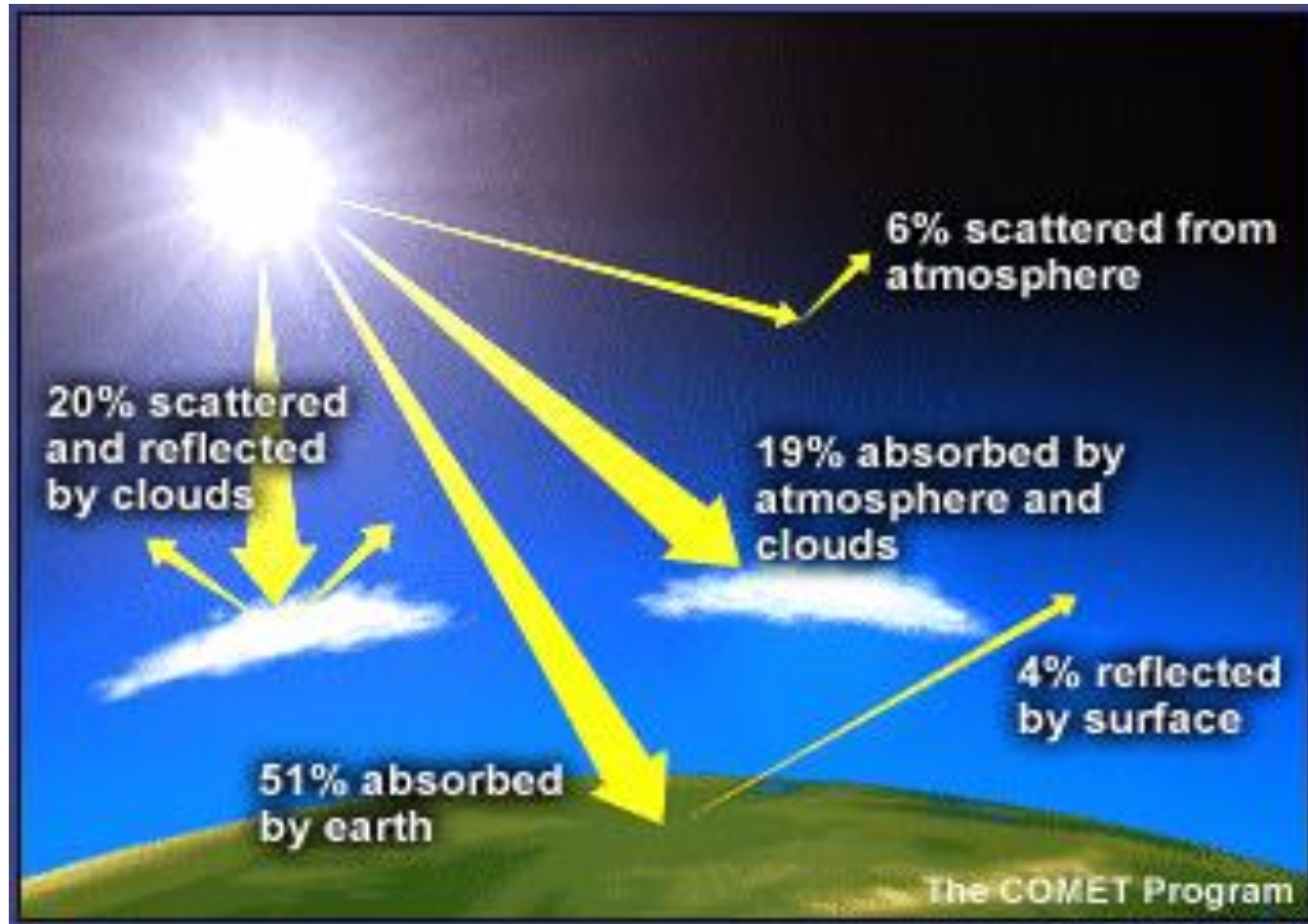
- $S_0 = 1370 \text{ W m}^{-2}$  normal to Sun  
 – Divide by 4 to average over Earth,  $342.5 \text{ W m}^{-2}$
- Albedo  $\approx 0.27-0.33$  (see Charlson)
- Thus  $T \approx 255 \text{ K} = -18 \text{ }^{\circ}\text{C}$

# Interpretation

- If the atmosphere didn't absorb radiation, the global average temperature should be about  $-18^{\circ}\text{C}$ .
- Near the surface, average air temperature is measured to be about  $16^{\circ}\text{C}$ .
- The discrepancy must be due to the role of the atmosphere in absorbing energy and storing it near the surface.
- This interaction between solar radiation and the atmosphere begins the processes of energy transfer that create climate

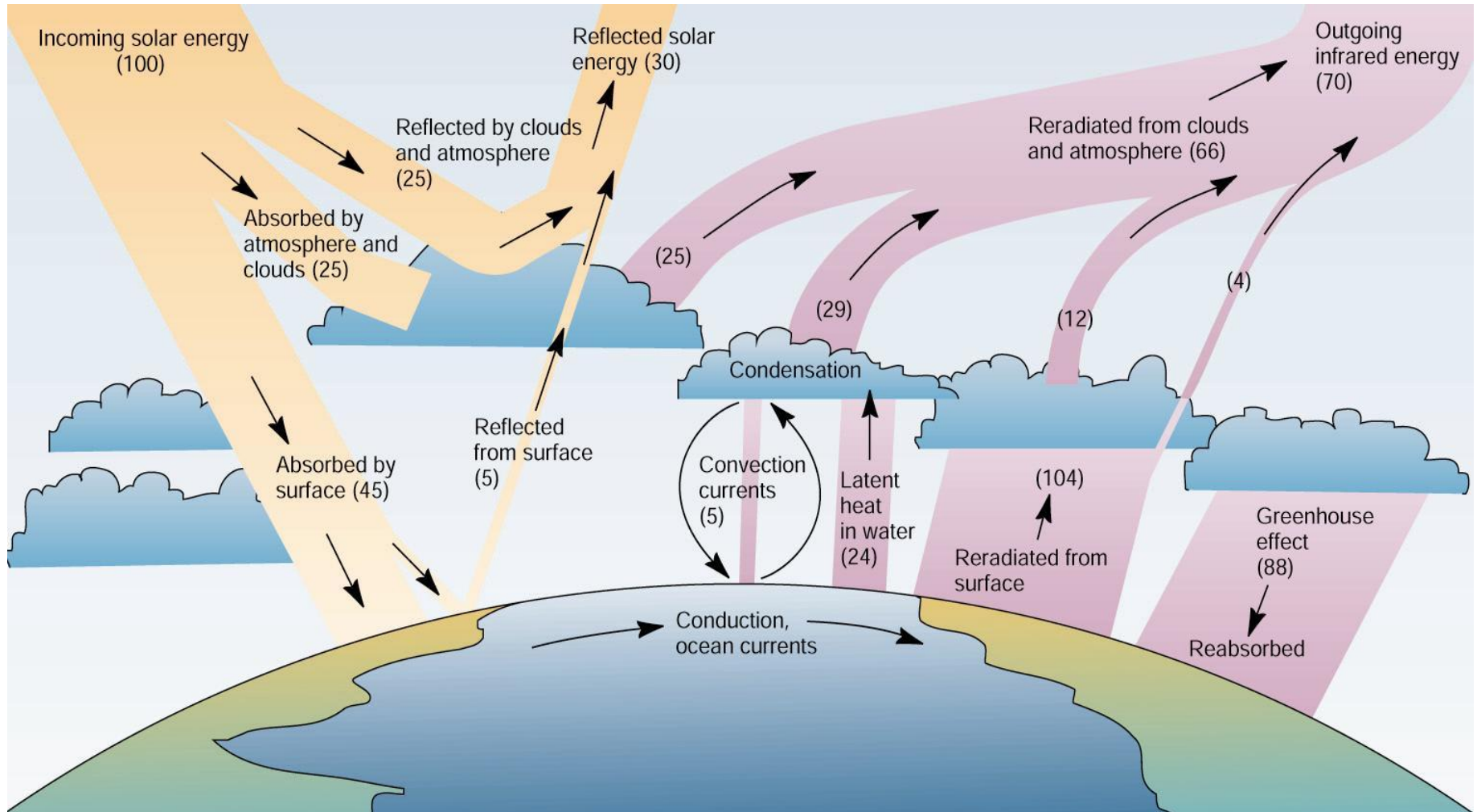


# Radiation balance - 1

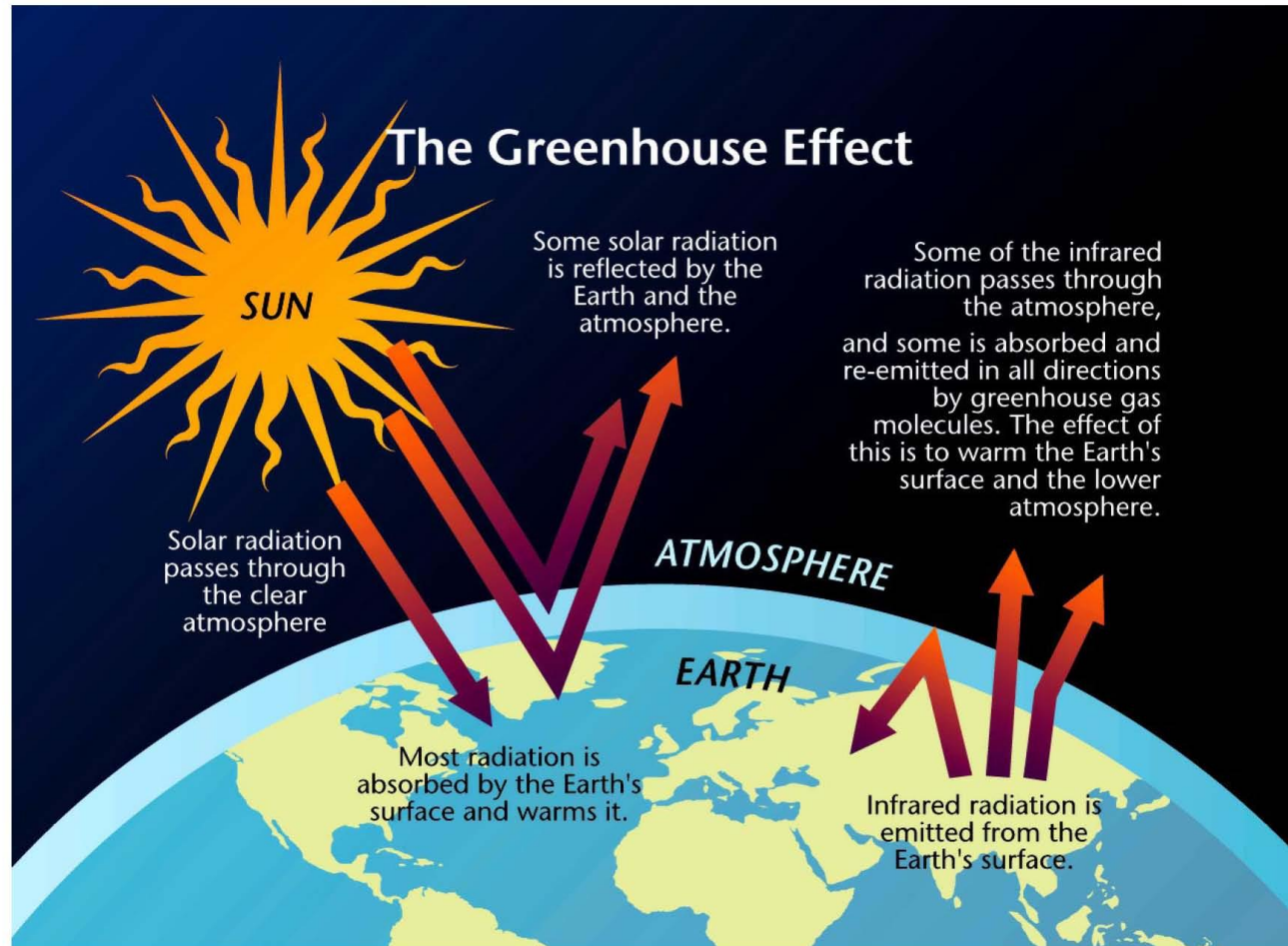


[www.windows.ucar.edu/earth/Atmosphere/images/...](http://www.windows.ucar.edu/earth/Atmosphere/images/...)

# Radiation balance - 2



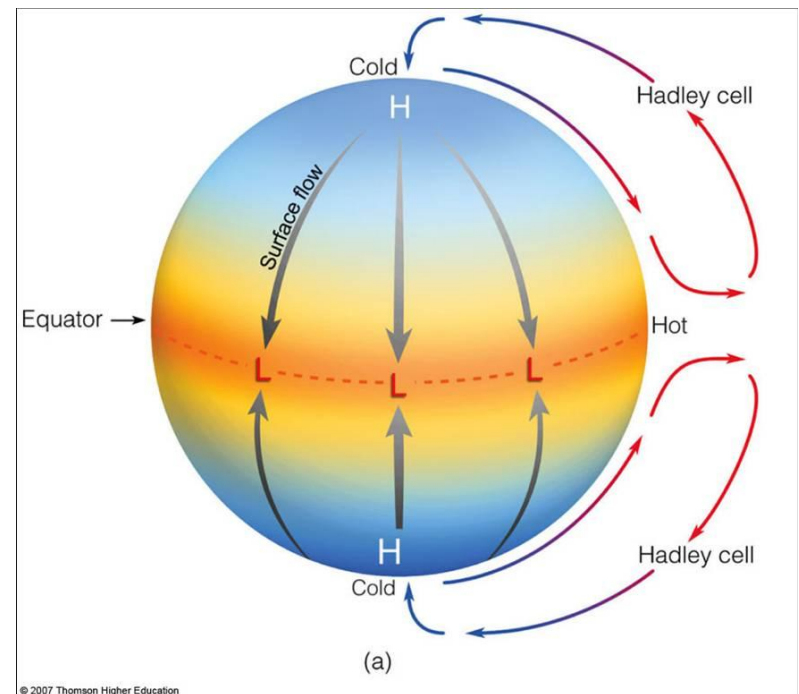
# Radiation balance - The greenhouse effect



# Wind and circulation patterns - 1

The major driving force of atmospheric circulation is solar heating, which on average is largest near the equator and smallest at the poles.

The atmospheric circulation transports energy polewards, thus reducing the resulting equator-to-pole temperature gradient. The mechanisms by which this is accomplished differ in tropical and extratropical latitudes.

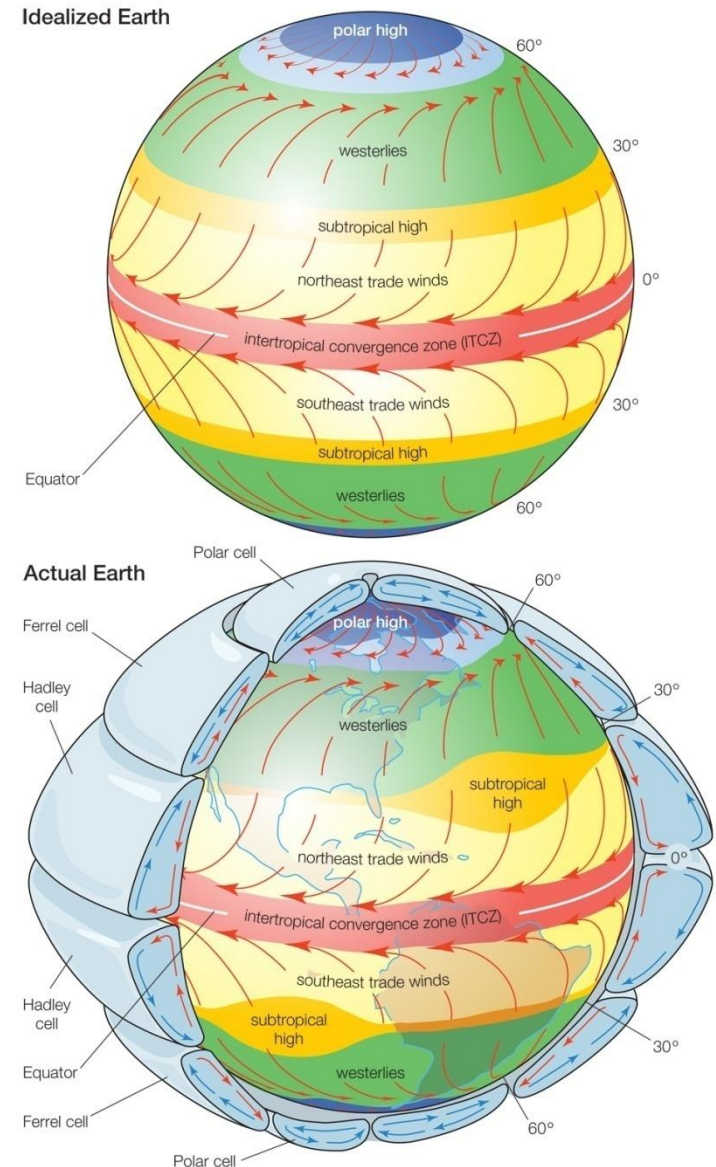




# Wind and circulation patterns - 2

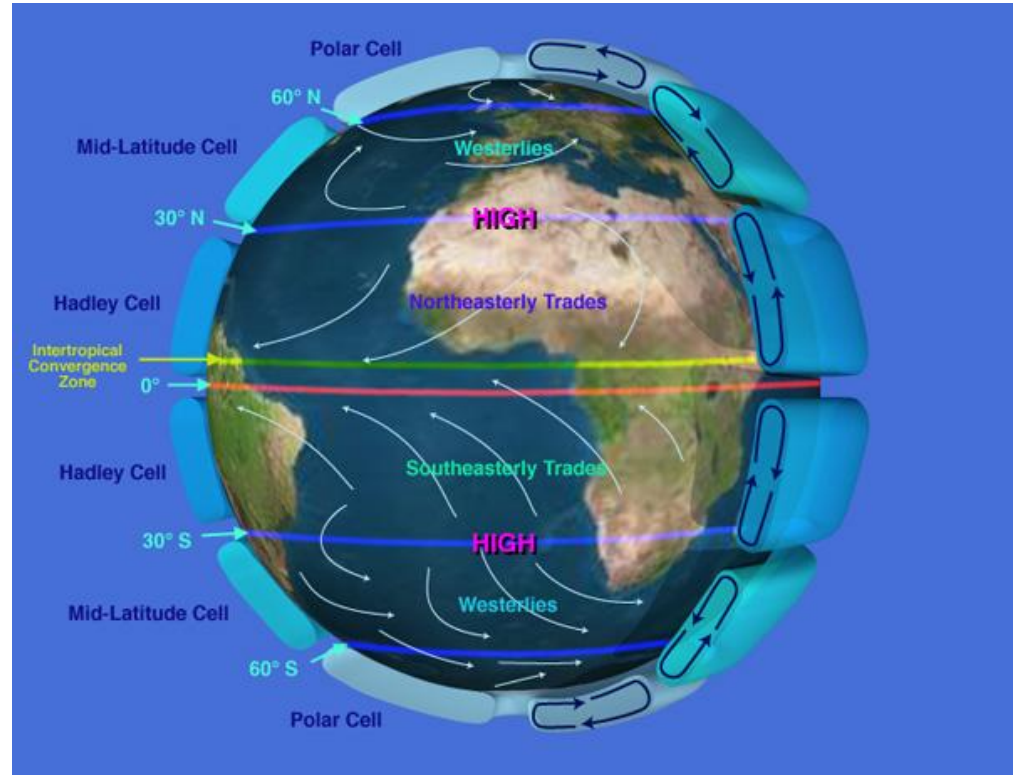
Between 30°N and 30°S latitude, this energy transport is accomplished by a relatively simple overturning circulation, with rising motion near the equator, poleward motion near the tropopause, sinking motion in the subtropics, and an equatorward return flow near the surface. In higher latitudes, the energy transport is instead accomplished by cyclones and anticyclones that cause relatively warm air to move polewards and cold air to move equatorwards in the same horizontal plane. The tropical overturning cell is referred to as the Hadley cell. Questions as to why it extends only to 30 degrees latitude and what determines its strength are at the heart of modern dynamical

[meteorology..](#)



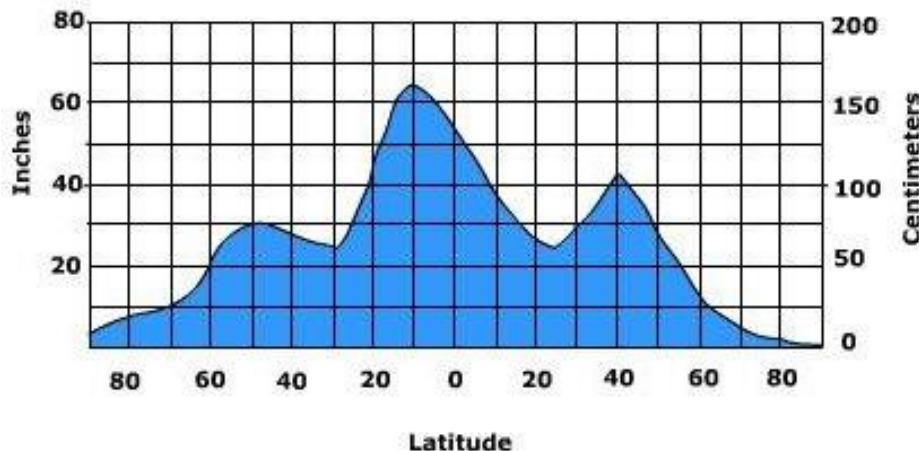
# Wind and circulation patterns - 3

The region in which the equatorward moving surface flows converge and rise is known as the intertropical convergence zone, or ITCZ, a high-precipitation band of thunderstorms. Having lost most of its water vapor to condensation and rain in the upward branch of the circulation, the descending air is dry. Low relative humidities are produced as the air is adiabatically warmed due to compression as it descends into a region of higher pressure. The subtropics are relatively free of the convection, or thunderstorms, that are common in the equatorial belt of rising motion. Many of the world's deserts are located in these subtropical latitudes.

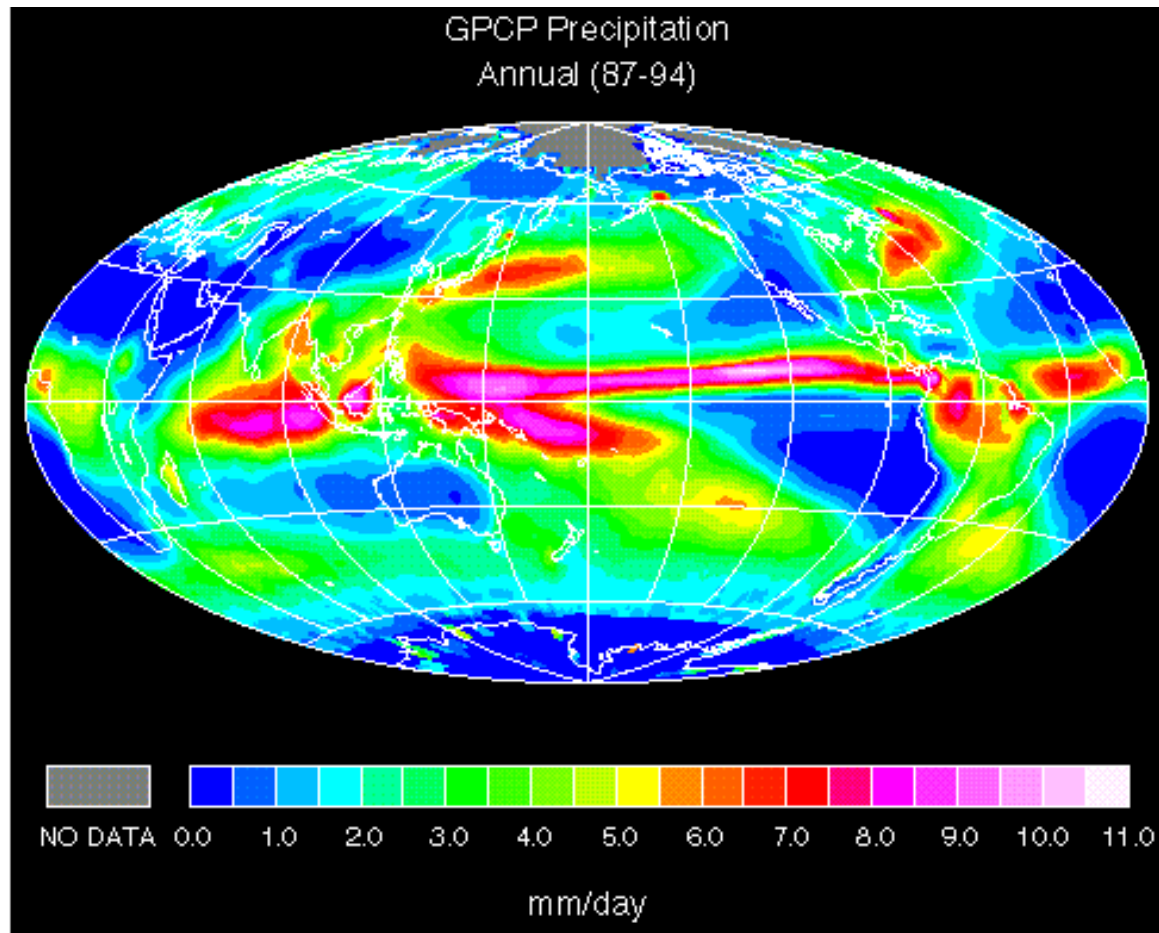


# Latitudinal distribution of precipitation

Precipitation near the equator is high due in part to the influence of the Intertropical Convergence Zone. Here, convection and low pressure dominate and provide lift for the air throughout much of the year. At about 30° north and south latitude precipitation decreases due to the presence of the subtropical high pressure systems. Precipitation increases in the midlatitudes where vastly contrasting air masses collide along weather fronts to cause precipitation. As one approaches the poles, precipitation decreases on account of the cold temperature and its associated low saturation point.

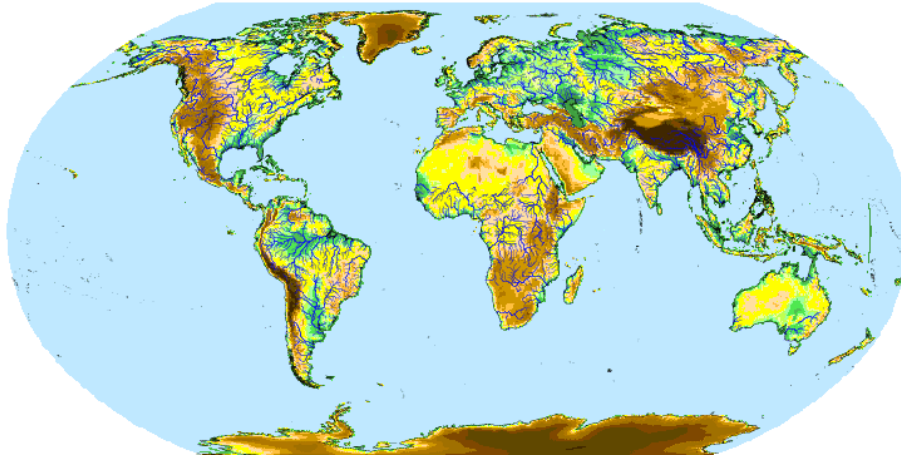


# Spatial distribution of precipitation (from satellites)





# Spatial distribution of precipitation (from raingauges)



Global altimetry

